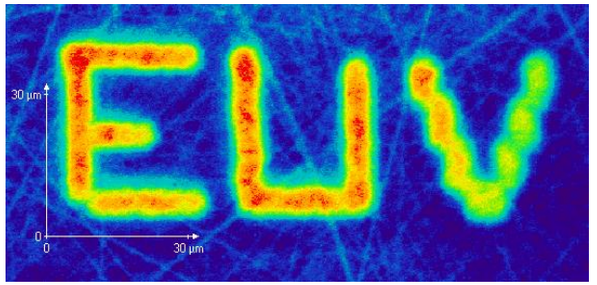

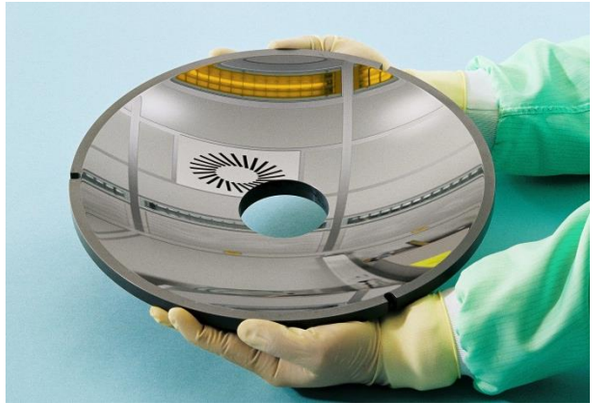

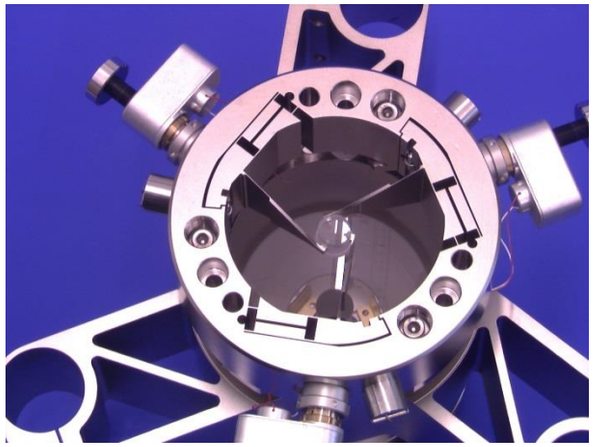

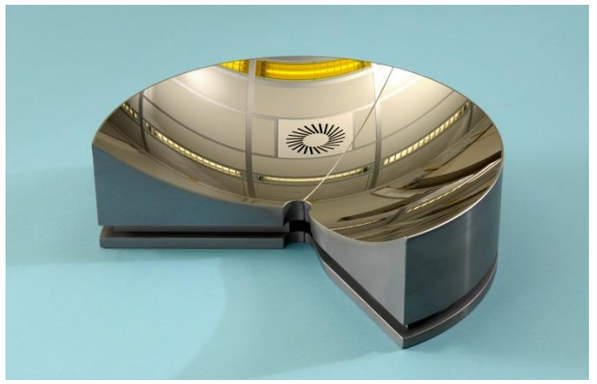

Enhanced Performance of Multilayer Optics for Water Window Microscopy

2016 International Workshop on EUV and soft X-Ray Sources

Torsten Feigl, Hagen Pauer, Tobias Fiedler, Marco Perske

optiX fab GmbH, Jena

Amsterdam, November 9, 2016

optiX fab.

Outline

- Introduction
- Multilayer collector mirror for 2.478 nm
- Multilayer turning mirror for 2.738 nm
- Summary

optiX fab.

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optiX fab.

Information about optiX fab.

2013: August 1st: Operations start @ **optiX fab.**

Nov 8, 2016: Delivery of **4685 EUV and X-ray mirrors** to customers

- Mission: Fabrication of customized EUV optics and optical components for EUVL, synchrotron and FEL beamlines, metrology, R&D, HHG sources, and **water window microscopy**.

- Team:


Torsten Feigl

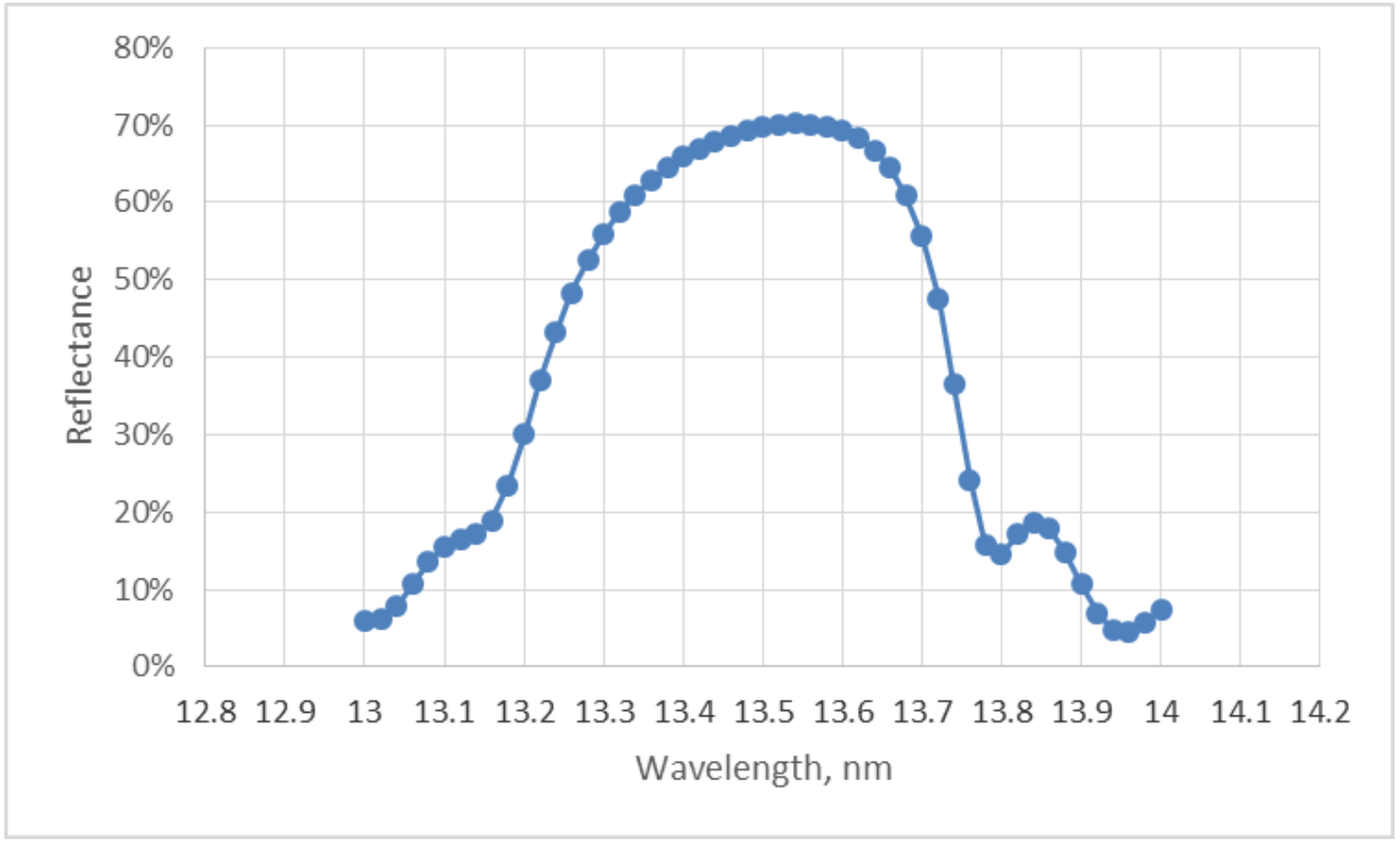

Marco Perske


Hagen Pauer


Tobias Fiedler

optiX fab.

Multilayers for 13.5 nm



R = 70.12 %

λ = 13.48 nm

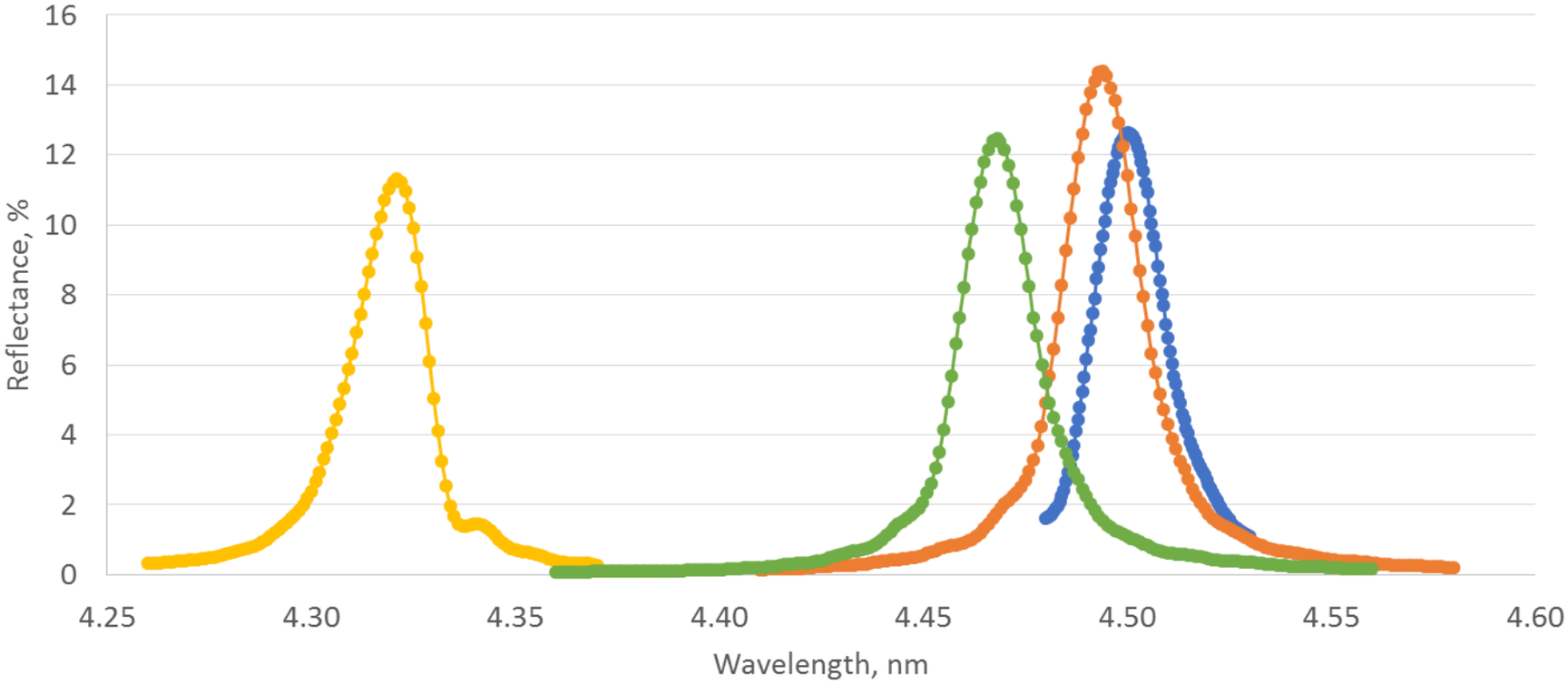
FWHM = 0.528 nm

AOI = 5 deg.

Measured @PTB Berlin

optiX fab.

Multilayers for 4.2 … 4.6 nm

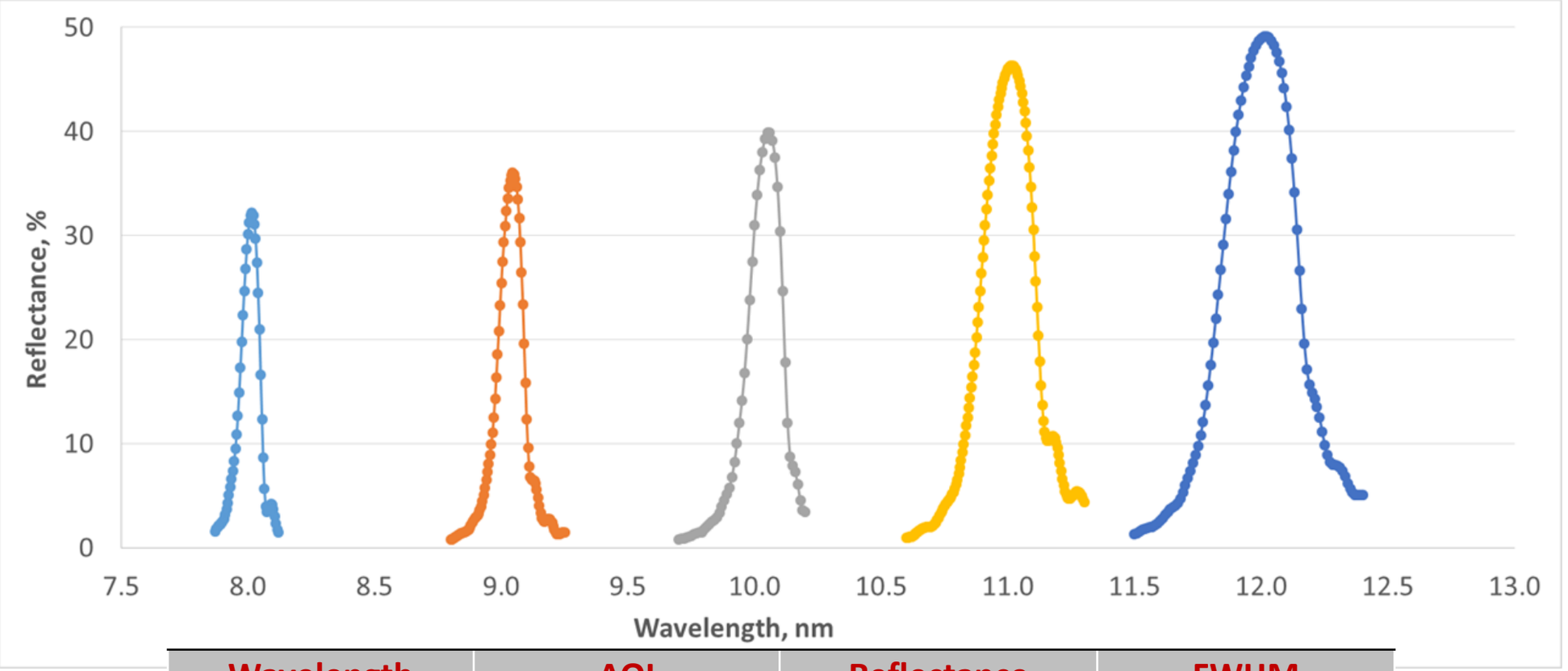


Wavelength	AOI	Reflectance	FWHM	Remarks
4.32 nm	1.5 deg	11.32 %	0.020 nm	
4.47 nm	14.3 deg	12.42 %	0.021 nm	unpolarized
4.49 nm	14.3 deg	14.39 %	0.022 nm	s-polarized
4.50 nm	3.0 deg	12.64 %	0.020 nm	

Measured
@PTB Berlin

optiX fab.

Multilayers for 8 … 12 nm

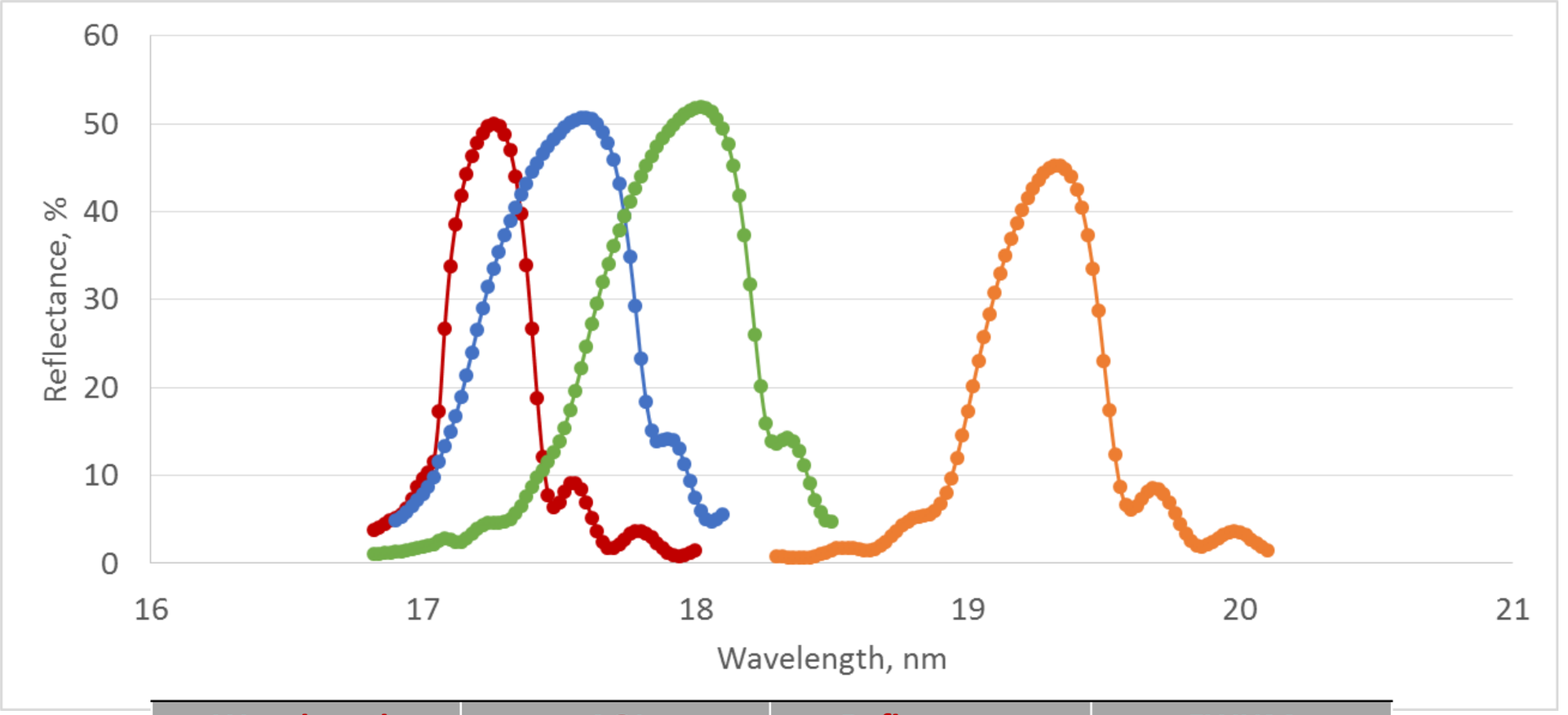


Wavelength	AOI	Reflectance	FWHM
8.0 nm	5 deg	32.2 %	0.08 nm
9.0 nm	5 deg	36.0 %	0.11 nm
10.0 nm	5 deg	39.9 %	0.15 nm
11.0 nm	5 deg	46.3 %	0.23 nm
12.0 nm	5 deg	49.1 %	0.33 nm

Measured @PTB Berlin

optiX fab.

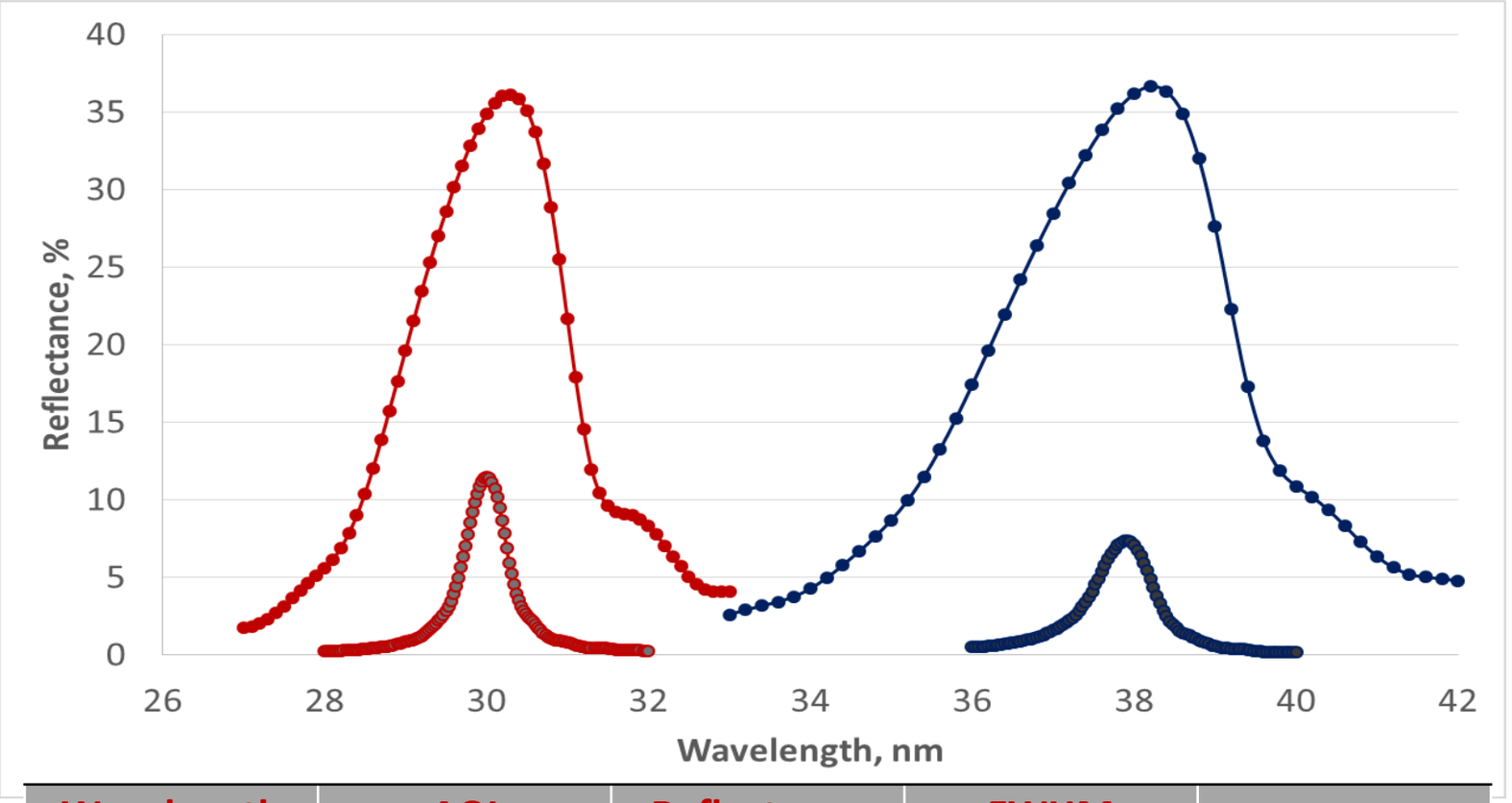
Multilayers for 17 … 20 nm



Wavelength	AOI	Reflectance	FWHM
17.24 nm	5 deg	50.0 %	0.33 nm
17.49 nm	5 deg	50.7 %	0.60 nm
17.91 nm	5 deg	51.9 %	0.61 nm
19.27 nm	5 deg	45.3 %	0.47 nm

optiX fab.

Narrowband Multilayers for 30 … 38 nm

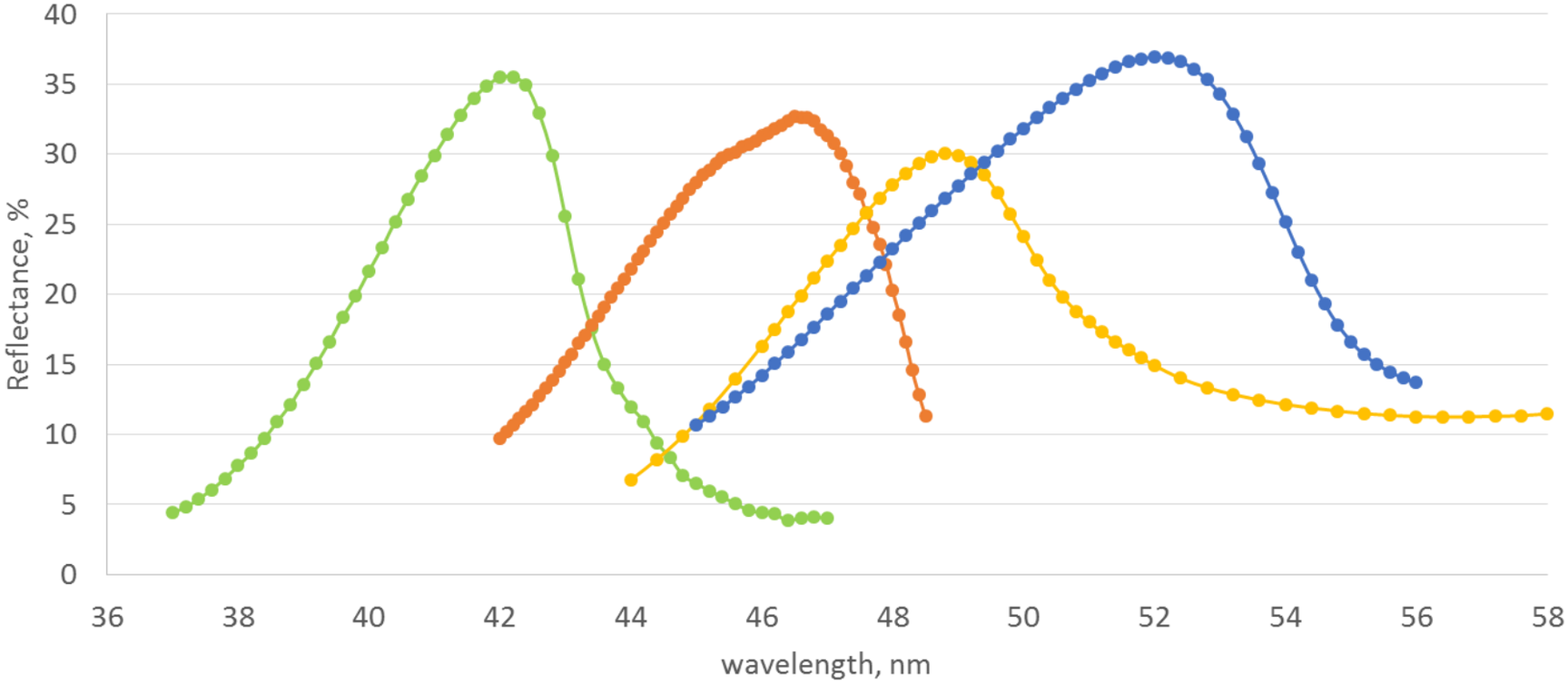


Wavelength	AOI	Reflectance	FWHM	ML Design
30.0 nm	5 deg	36.1 %	2.17 nm	
30.0 nm	15 deg	11.5 %	0.60 nm	narrow band
37.9 nm	15 deg	36.7 %	3.28 nm	
38.0 nm	15 deg	7.4 %	0.86 nm	narrow band

Measured @PTB Berlin

optiX fab.

Multilayers for 42 … 52 nm

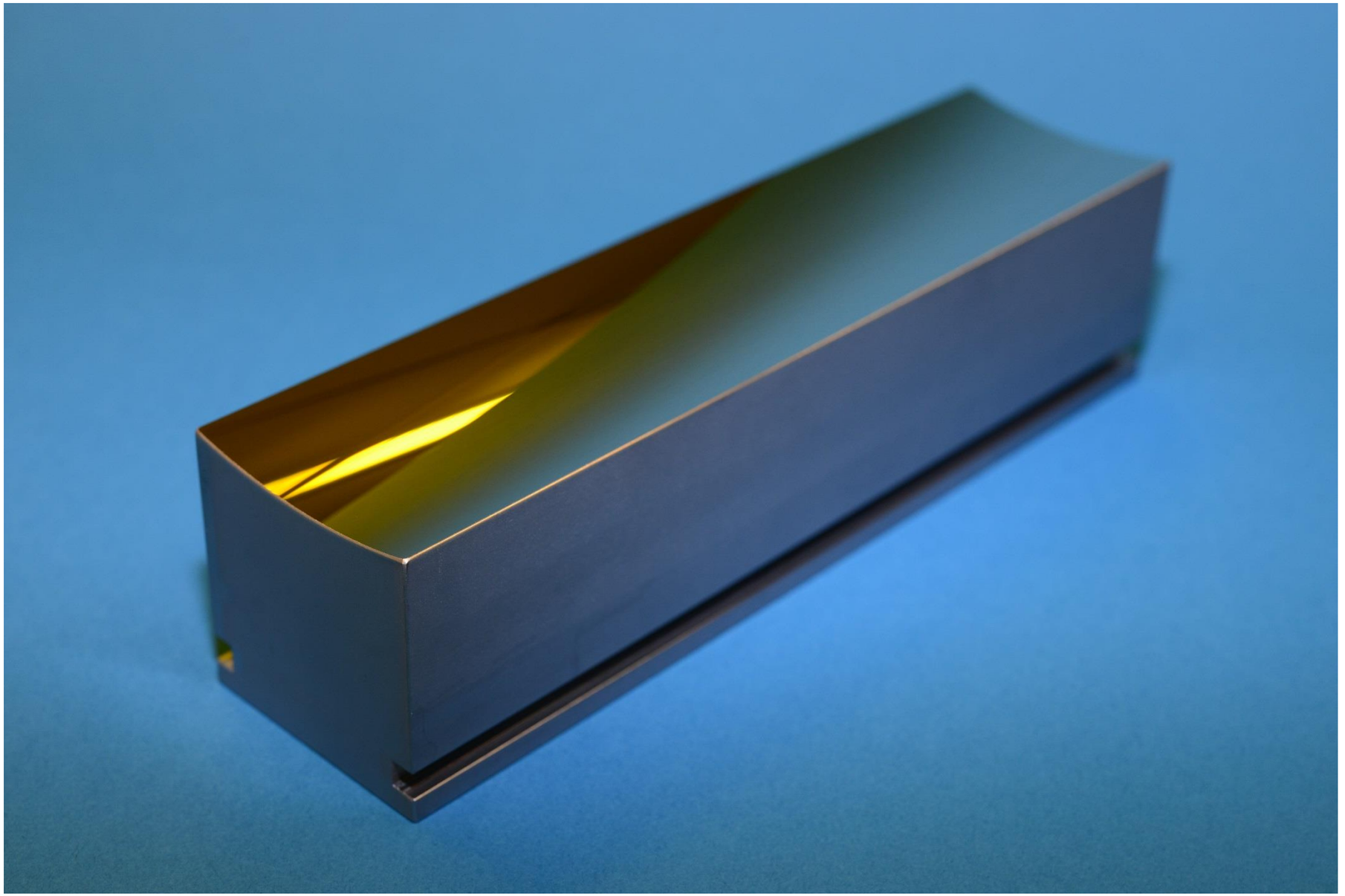


Wavelength	AOI	Reflectance	FWHM
41.5 nm	1.5 deg	35.6 %	3.86 nm
45.7 nm	1.5 deg	32.6 %	5.03 nm
49.1 nm	2.0 deg	30.1 %	5.60 nm
52.0 nm	1.5 deg	36.9 %	7.80 nm

Measured @PTB Berlin

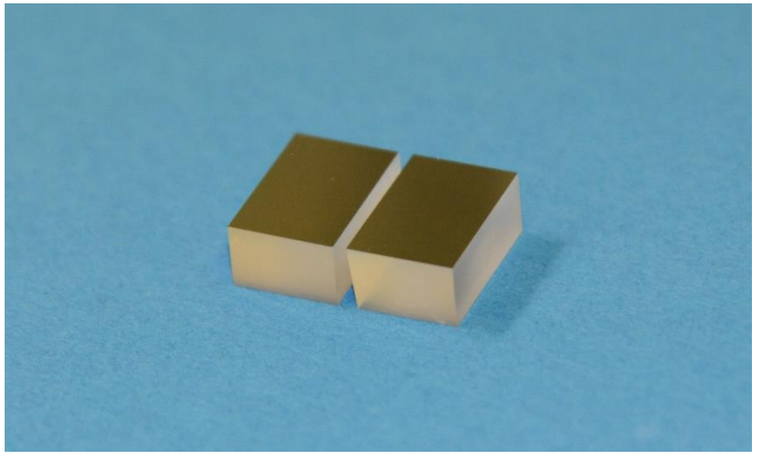
optiX fab.

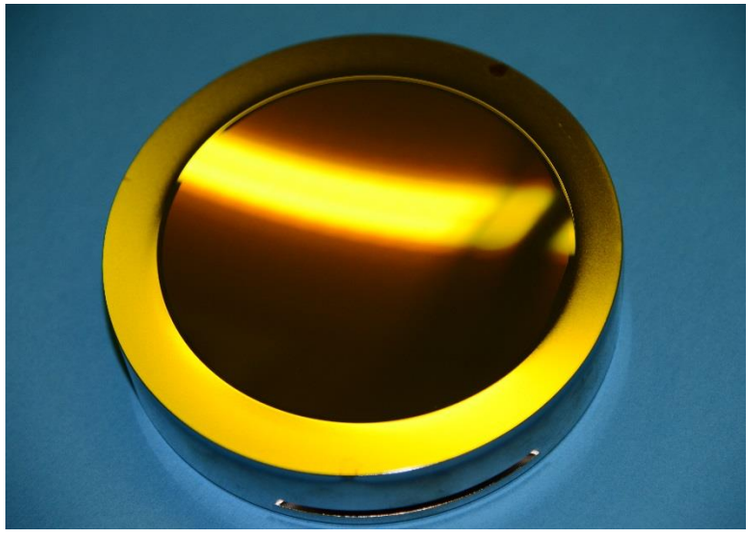
Gold coated synchrotron optics



optiX fab.

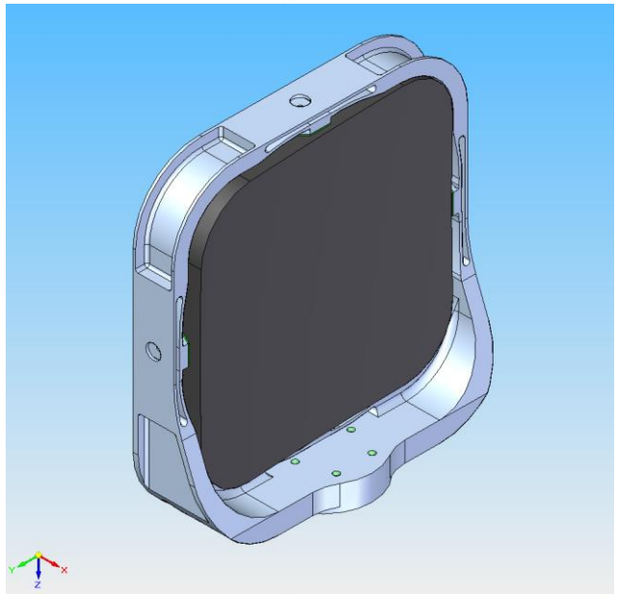
EUV optics – made by optiX fab





optiX fab.

SPICE primary mirror for Solar Orbiter for 70 … 105 nm



optiX fab.

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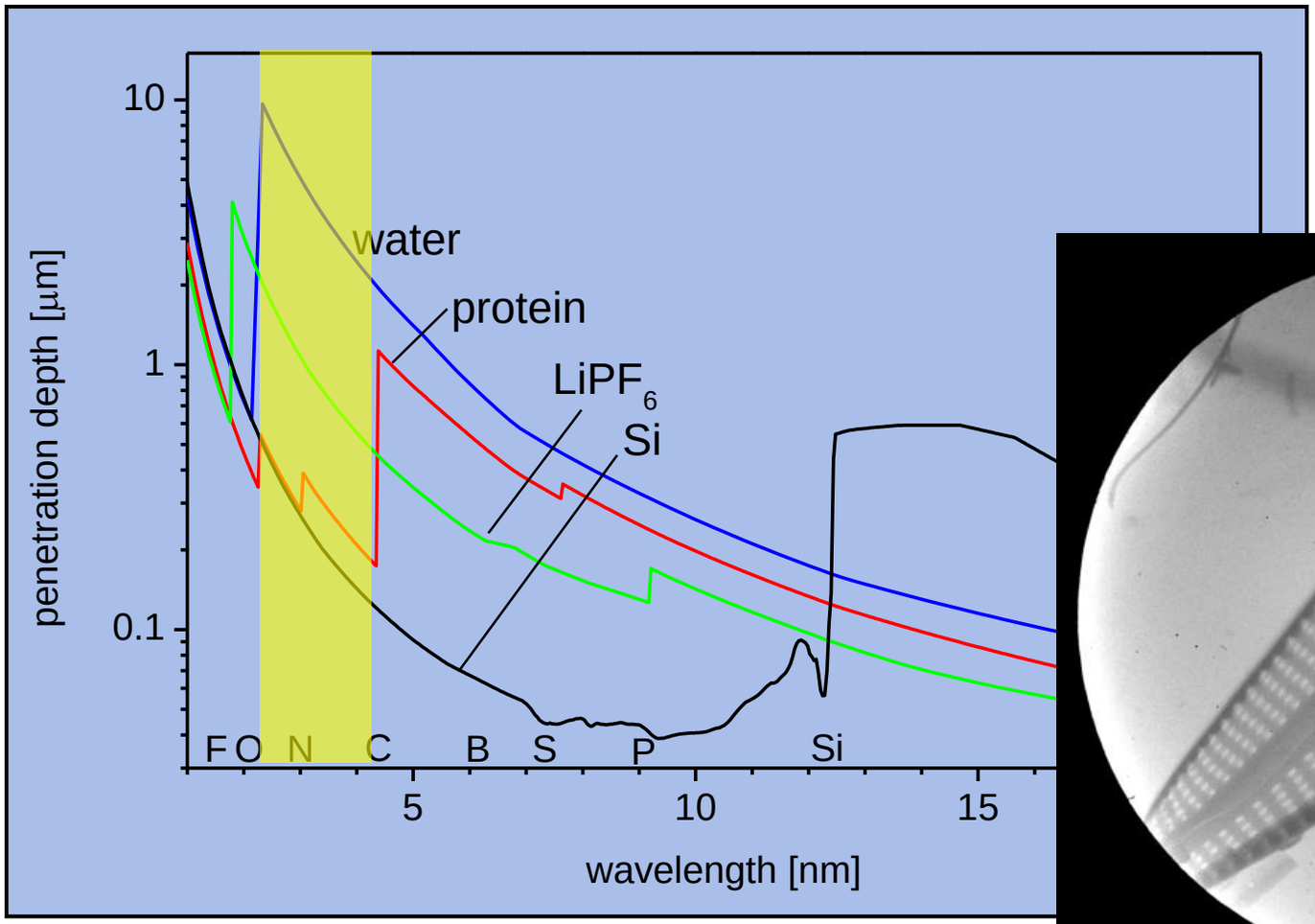
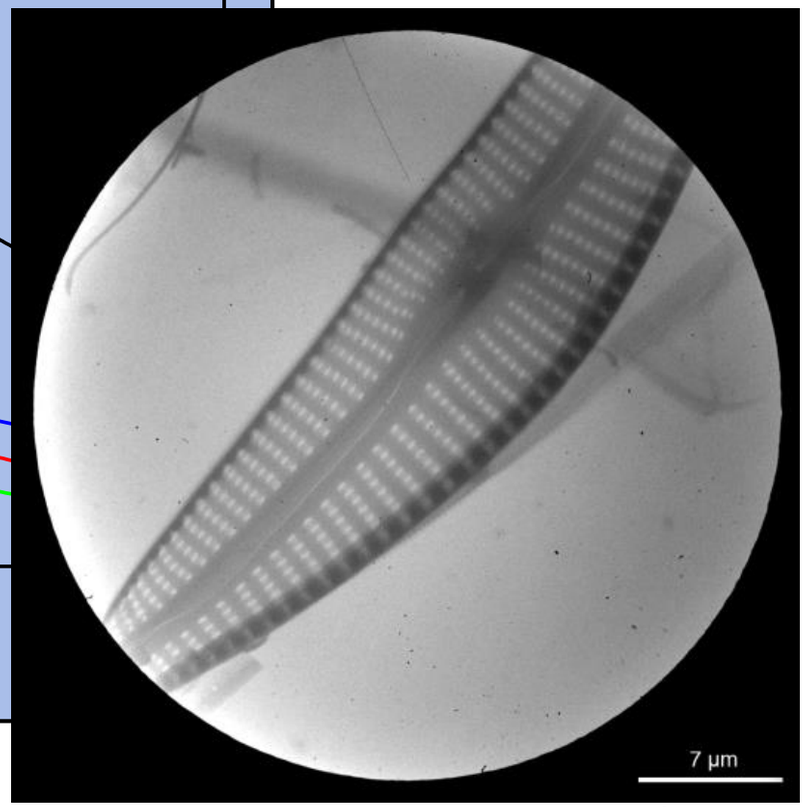
optiX fab.

Water window microscopy

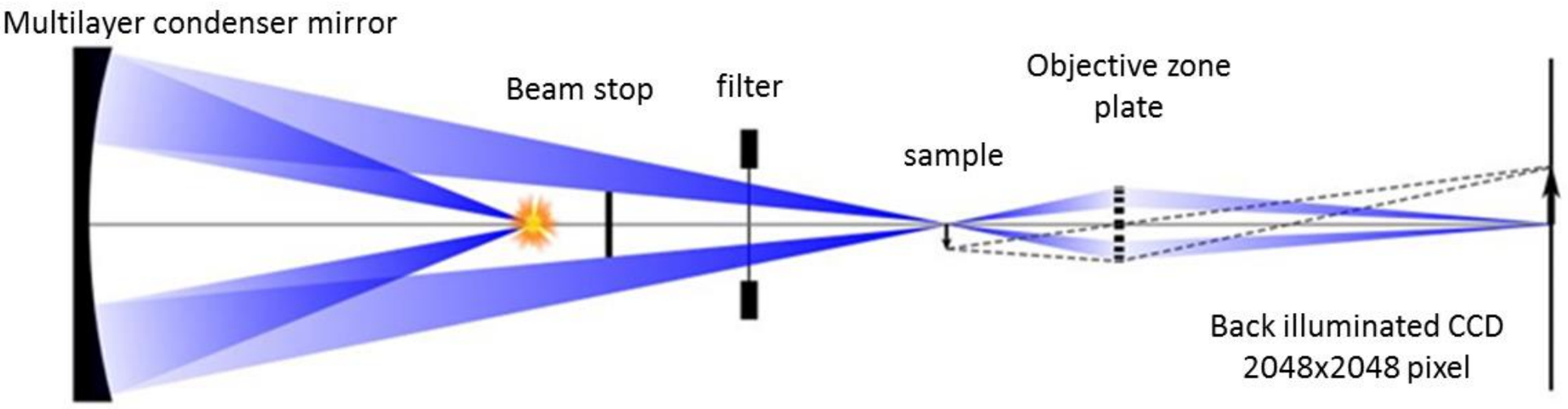




diatom

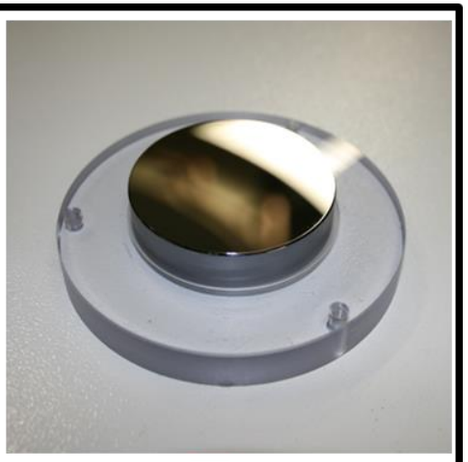
optiX fab.

Laboratory Transmission X-ray Microscope @ KTH Stockholm

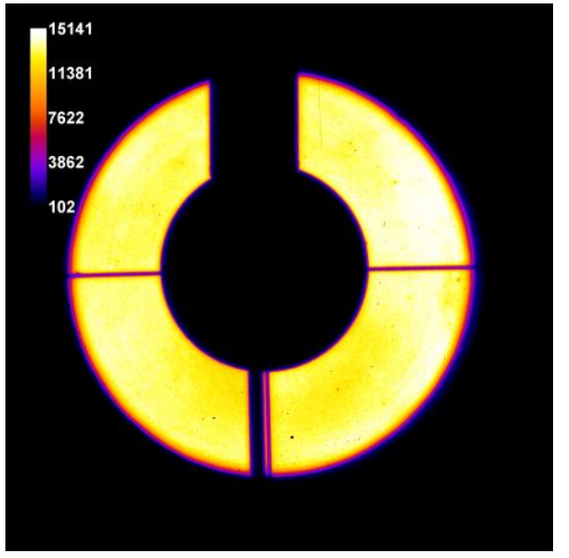


Multilayer condenser

Coating: Cr / V
Wavelength:
(2.478 ± 0.01) nm
Bandwidth: 8 pm
mean reflectivity:
Up to 0.6 %
Radial aperture:
54 mm
Throughput:
> $2*10^{-4}$ sr

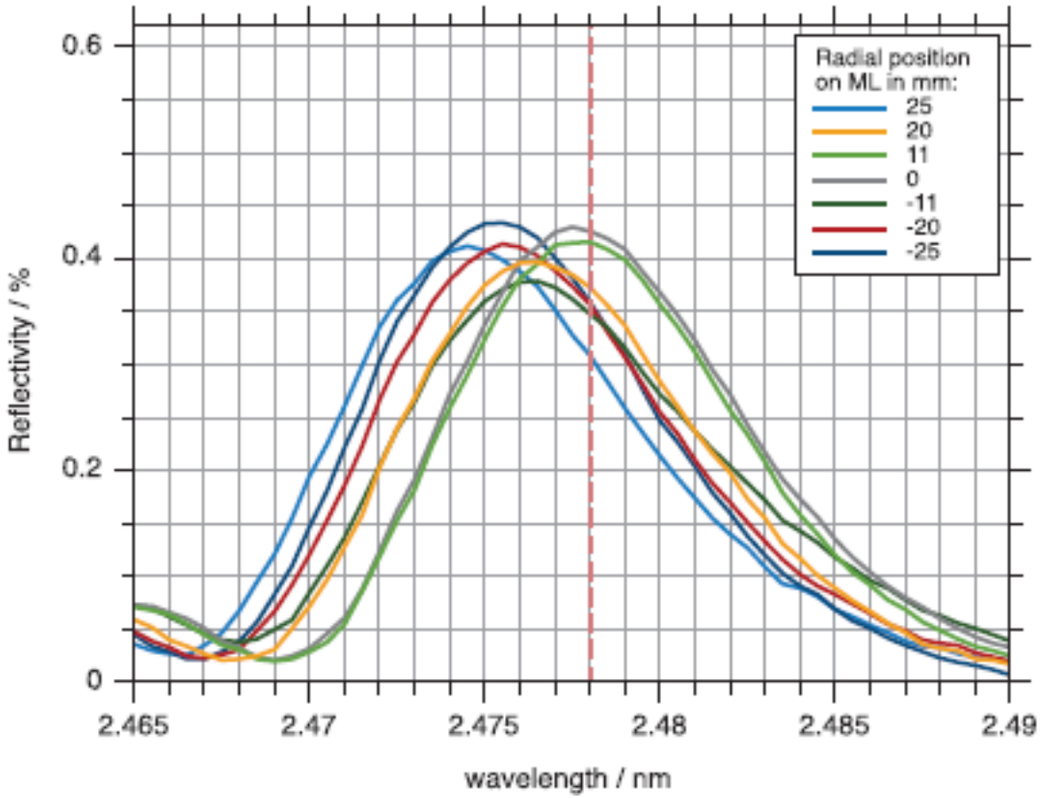


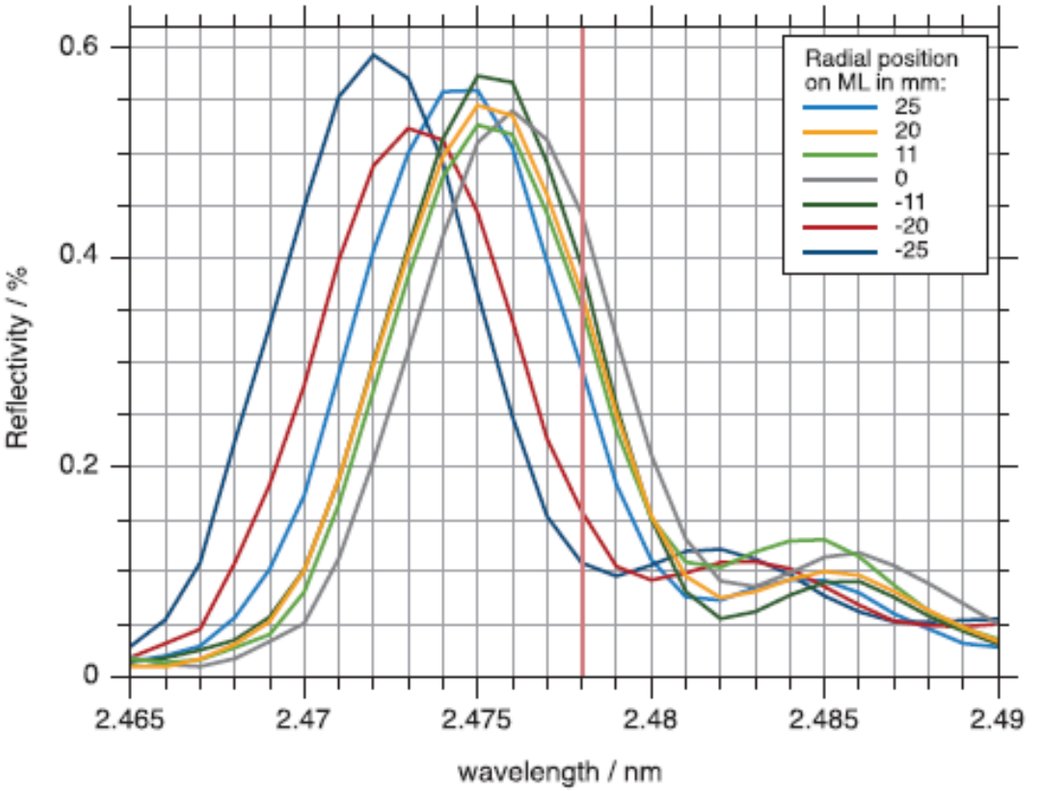
Fraunhofer IOF



optiX fab.

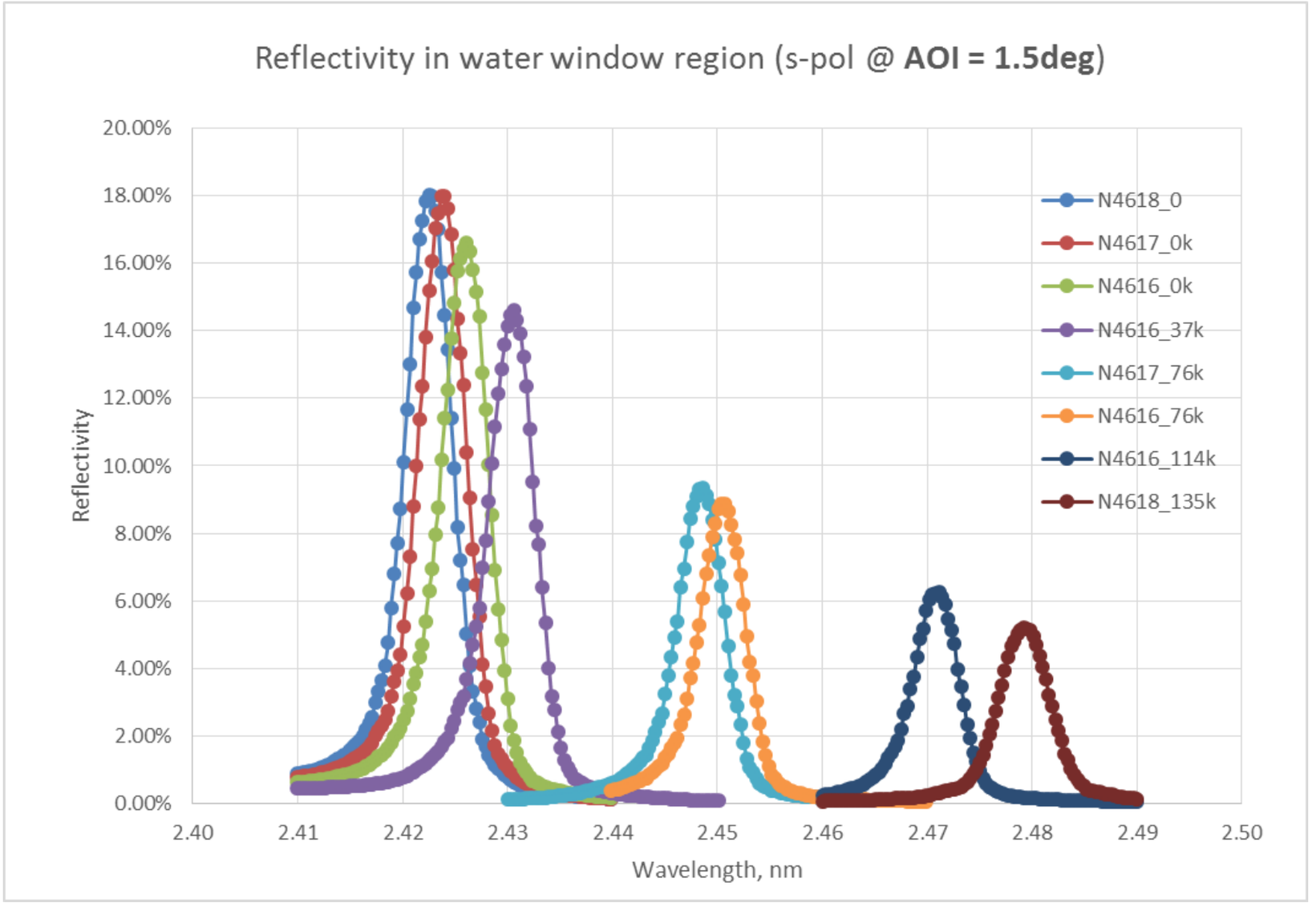
Water window multilayer collector: optical performance





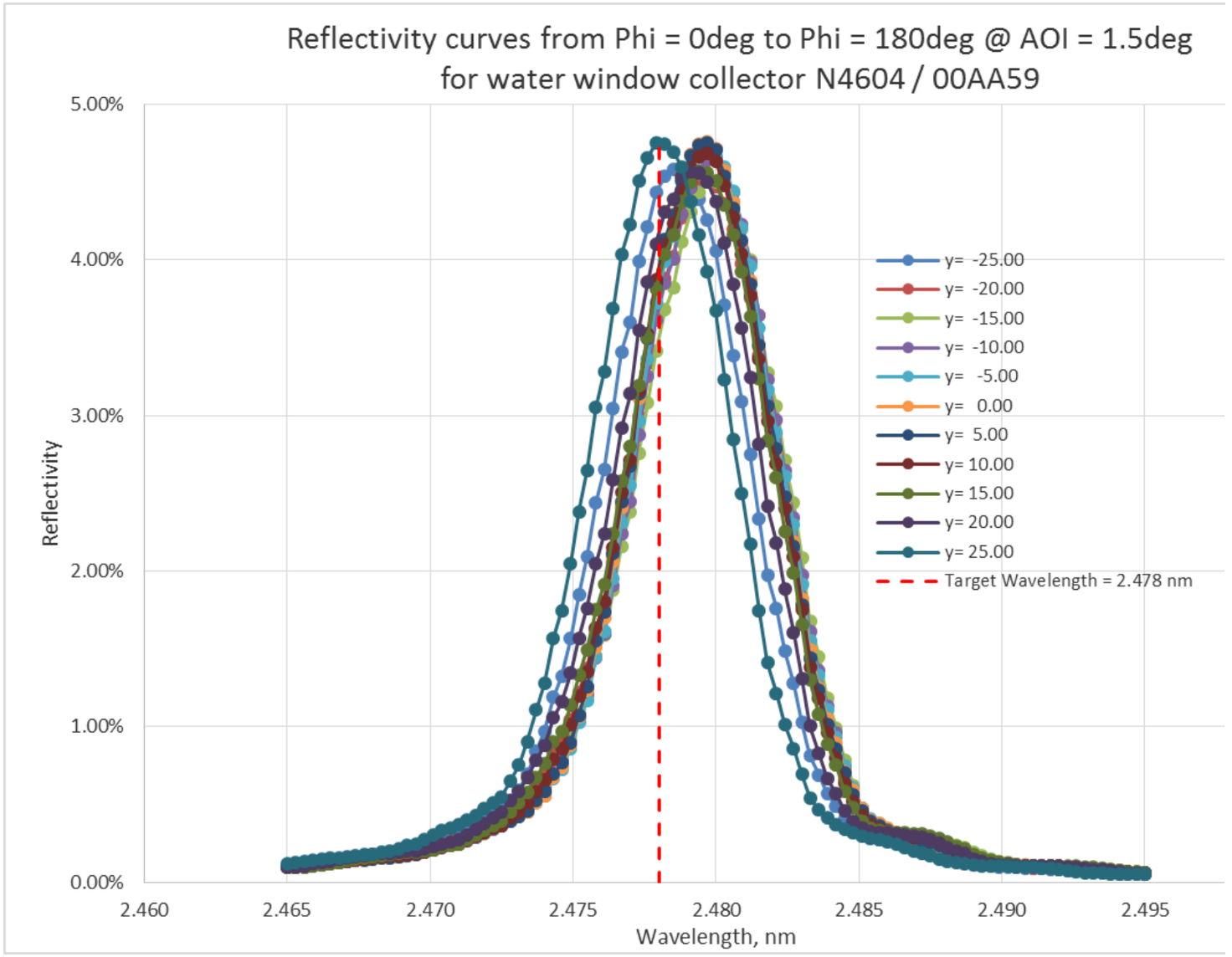
optiX fab.

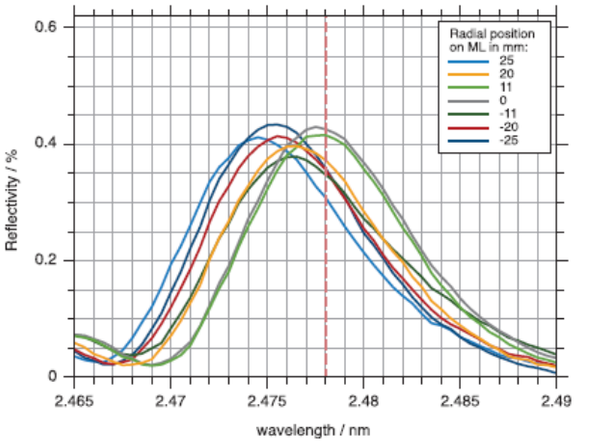
Multilayer development for water window collector

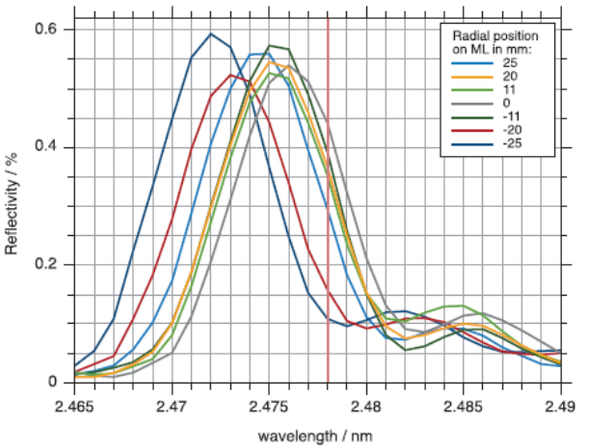


optiX fab.

Collector mirror – 2015 status: EUV reflectance at different radii

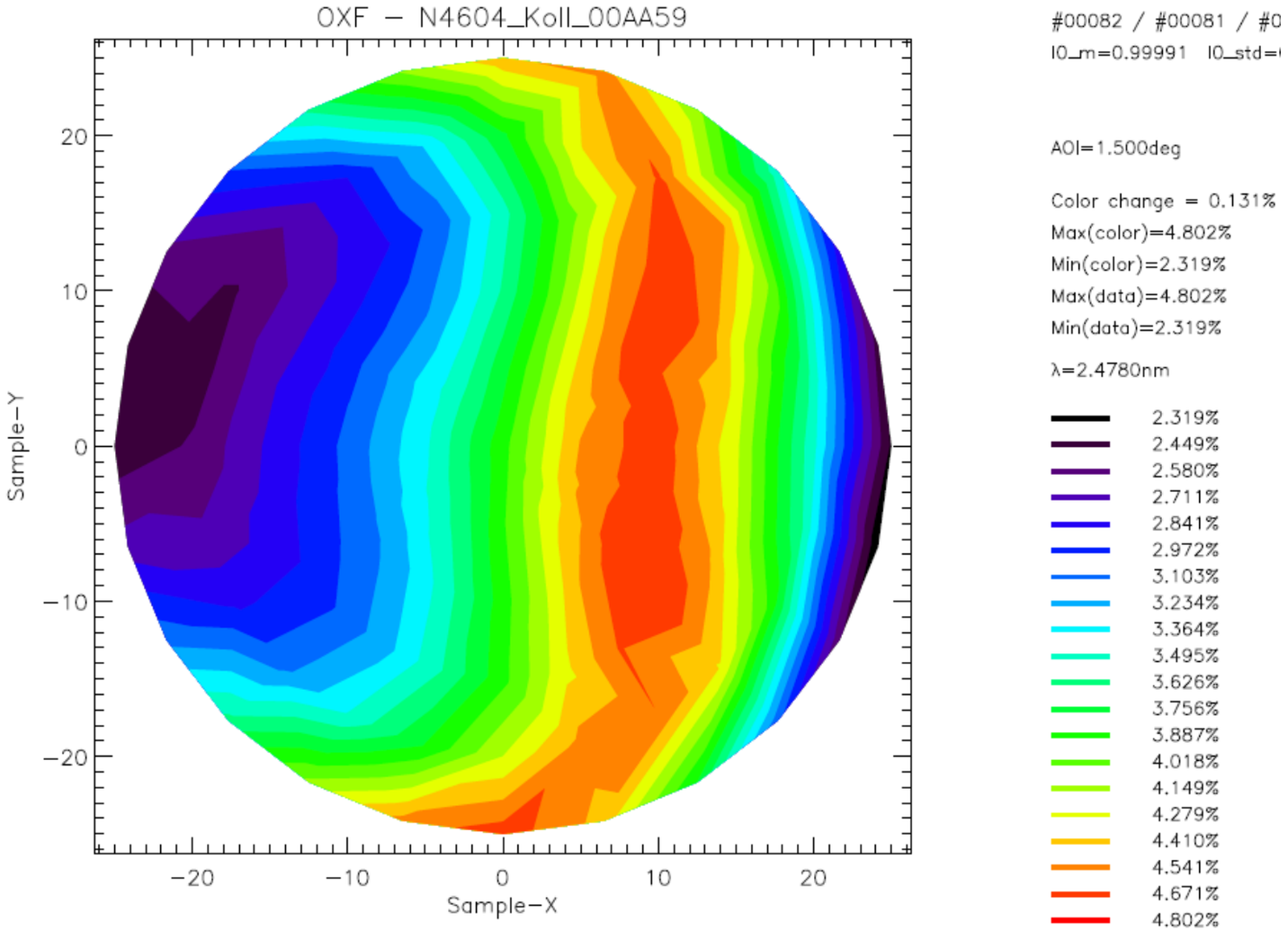






optiX fab.

Collector mirror – 2015 status: Reflectance mapping at λ = 2.478 nm



#00082 / #00081 / #0
I0_m=0.99991 I0_std=

AOI=1.500deg

Color change = 0.131%
Max(color)=4.802%
Min(color)=2.319%
Max(data)=4.802%
Min(data)=2.319%

λ=2.4780nm

2.319%
2.449%
2.580%
2.711%
2.841%
2.972%
3.103%
3.234%
3.364%
3.495%
3.626%
3.756%
3.887%
4.018%
4.149%
4.279%
4.410%
4.541%
4.671%
4.802%

R = 3.66 %

λ = 2.478 nm

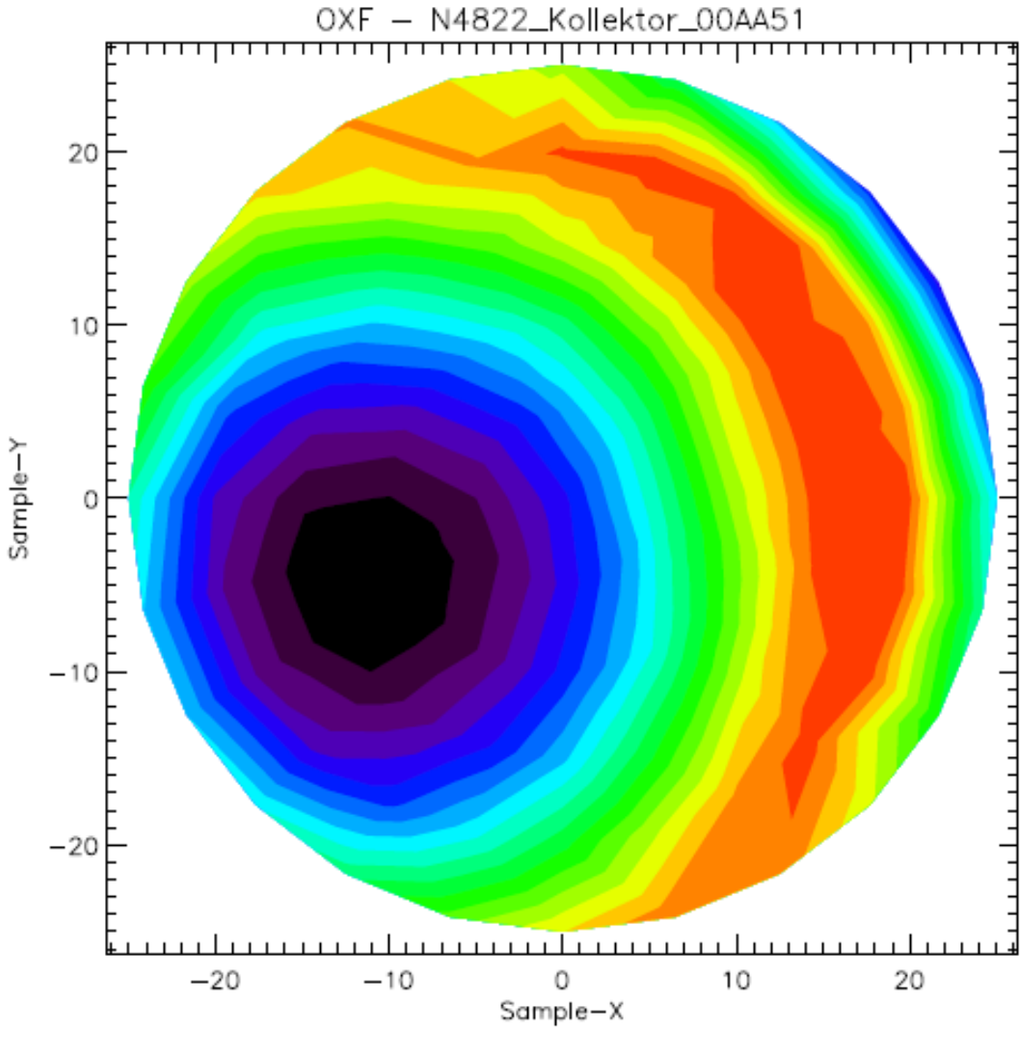
FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin

optiX fab.

Collector mirror – today: Reflectance mapping at λ = 2.478 nm



#00081 / #00080 / #00082
I0_m=0.99949 I0_std=0.00039

AOI=1.500deg

Color change = 0.11%
Max(color)=4.39%
Min(color)=2.28%
Max(data)=4.39%
Min(data)=2.28%

λ=2.4780nm

2.28%
2.39%
2.51%
2.62%
2.73%
2.84%
2.95%
3.06%
3.17%
3.28%
3.39%
3.51%
3.62%
3.73%
3.84%
3.95%
4.06%
4.17%
4.28%
4.39%

R = 3.60 %

(- 0.06 %)

λ = 2.478 nm

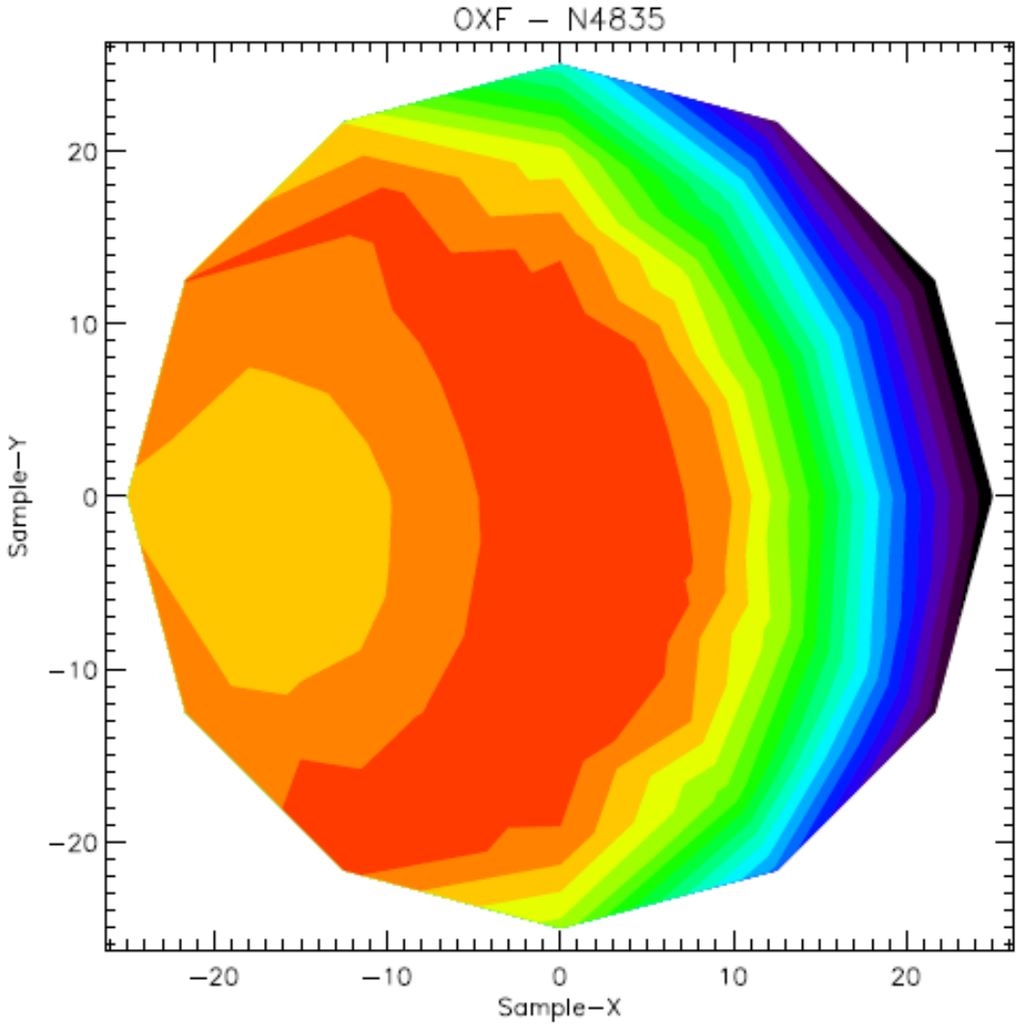
FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin

optiX fab.

Collector mirror – today: Reflectance mapping at λ = 2.478 nm



#00083 / #00082 / #00084
I0_m=0.99998 I0_std=0.00006

AOI=1.500deg

Color change = 0.22%
Max(color)=4.84%
Min(color)=0.67%
Max(data)=4.84%
Min(data)=0.67%

λ=2.4779nm

0.67%
0.89%
1.10%
1.32%
1.54%
1.76%
1.98%
2.20%
2.42%
2.64%
2.86%
3.08%
3.30%
3.52%
3.74%
3.96%
4.18%
4.40%
4.62%
4.84%

R = 3.78 %

(+ 0.12 %)

λ = 2.478 nm

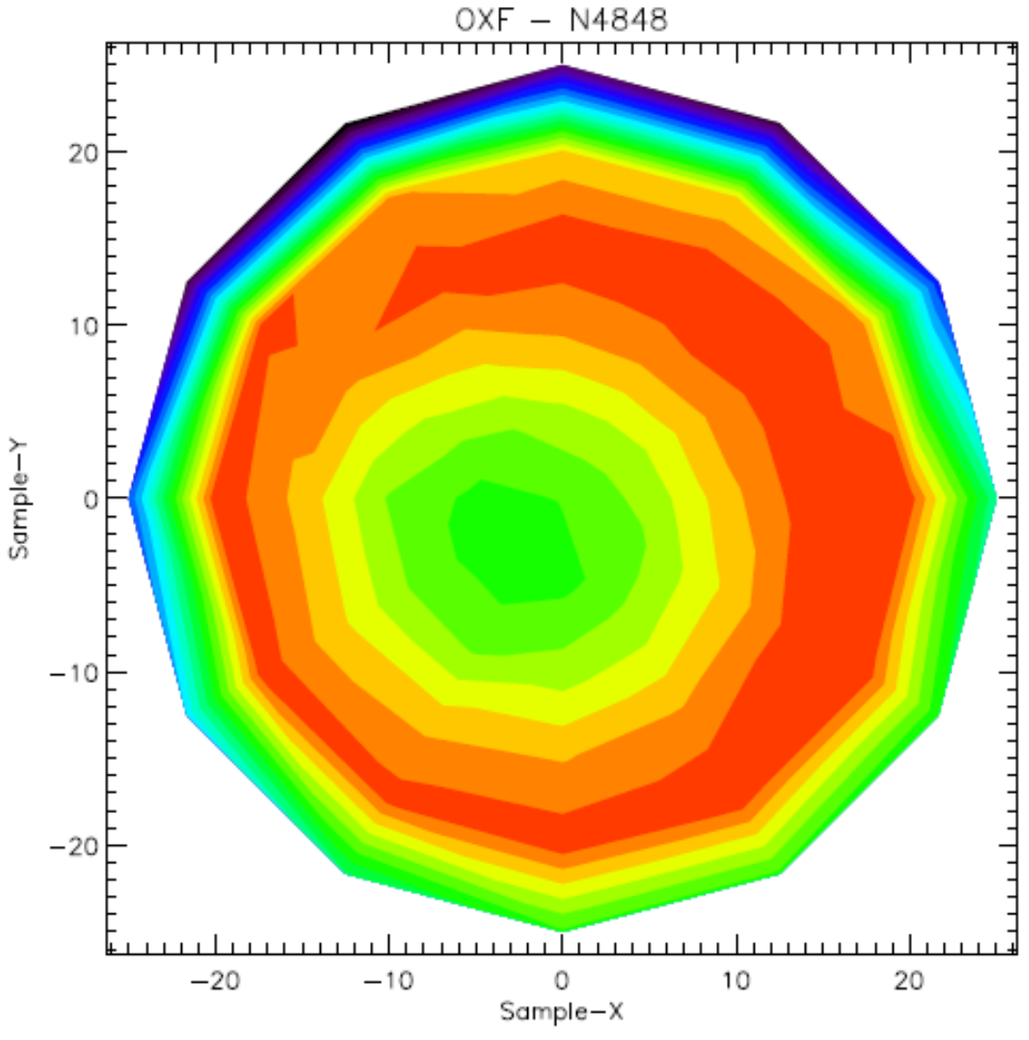
FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin

optiX fab.

Collector mirror – today: Reflectance mapping at λ = 2.478 nm



#00133 / #00132 / #00134
I0_m=0.99993 I0_std=0.00012

AOI=1.500deg

Color change = 0.08%
Max(color)=4.81%
Min(color)=3.38%
Max(data)=4.81%
Min(data)=3.38%

λ=2.4780nm

3.38%
3.45%
3.53%
3.60%
3.68%
3.75%
3.83%
3.90%
3.98%
4.06%
4.13%
4.21%
4.28%
4.36%
4.43%
4.51%
4.58%
4.66%
4.73%
4.81%

R = 4.51 %

(+ 0.85 %)

λ = 2.478 nm

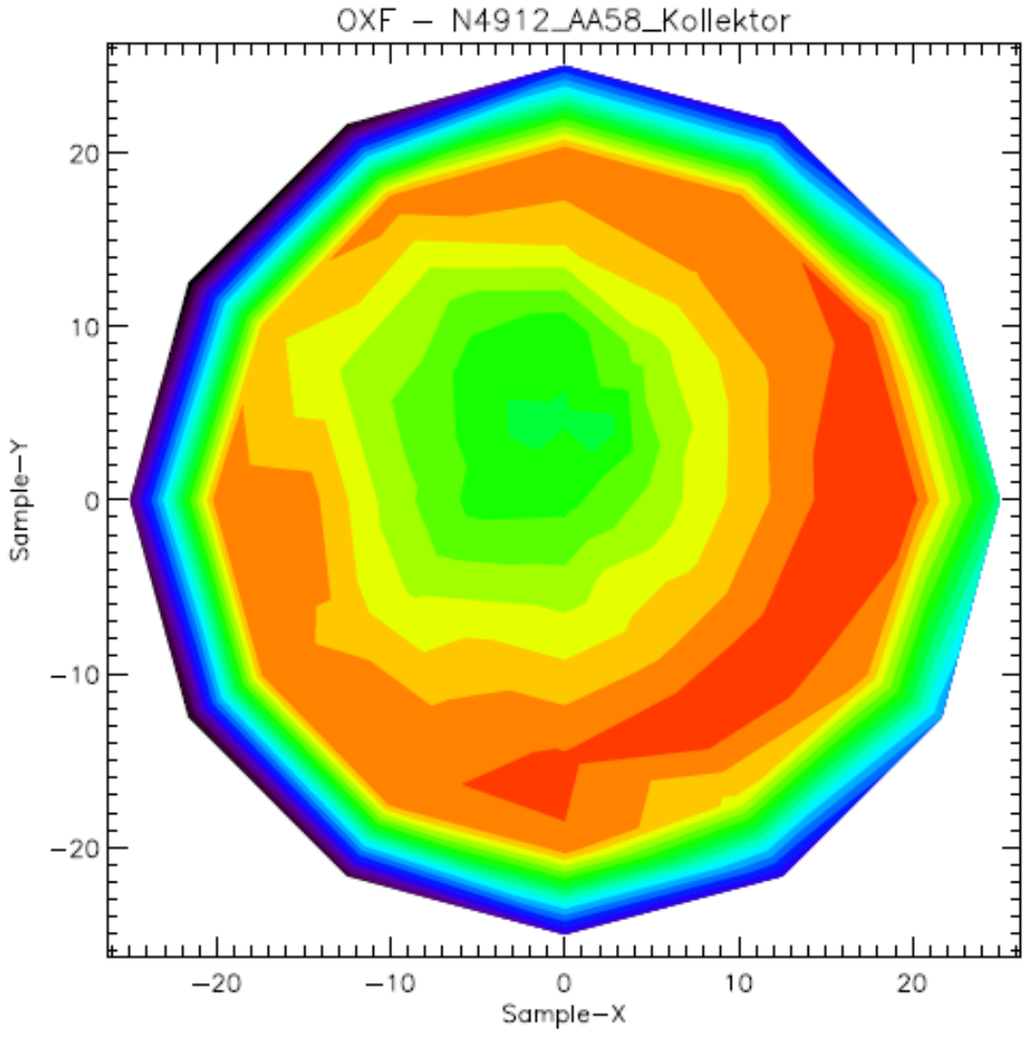
FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin

optiX fab.

Collector mirror – today: Reflectance mapping at λ = 2.478 nm



#00090 / #00089 / #00091
I0_m=0.99936 I0_std=0.00014

AOI=1.500deg

Color change = 0.041%
Max(color)=4.787%
Min(color)=4.013%
Max(data)=4.787%
Min(data)=4.013%

λ=2.478nm

4.013%
4.054%
4.095%
4.136%
4.176%
4.217%
4.258%
4.299%
4.339%
4.380%
4.421%
4.462%
4.502%
4.543%
4.584%
4.625%
4.665%
4.706%
4.747%
4.787%

R = 4.58 %

(+ 0.92 %)

λ = 2.478 nm

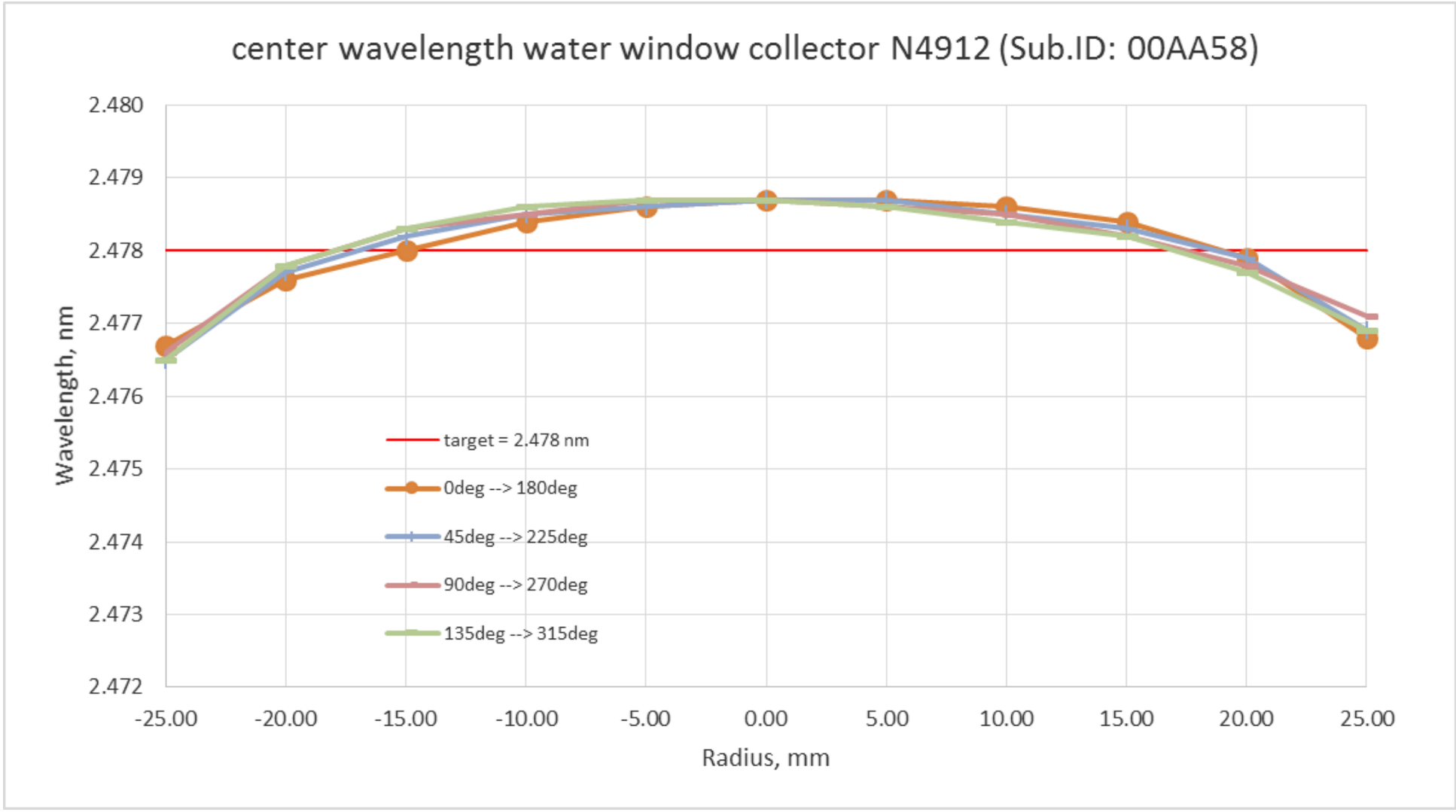
FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin

optiX fab.

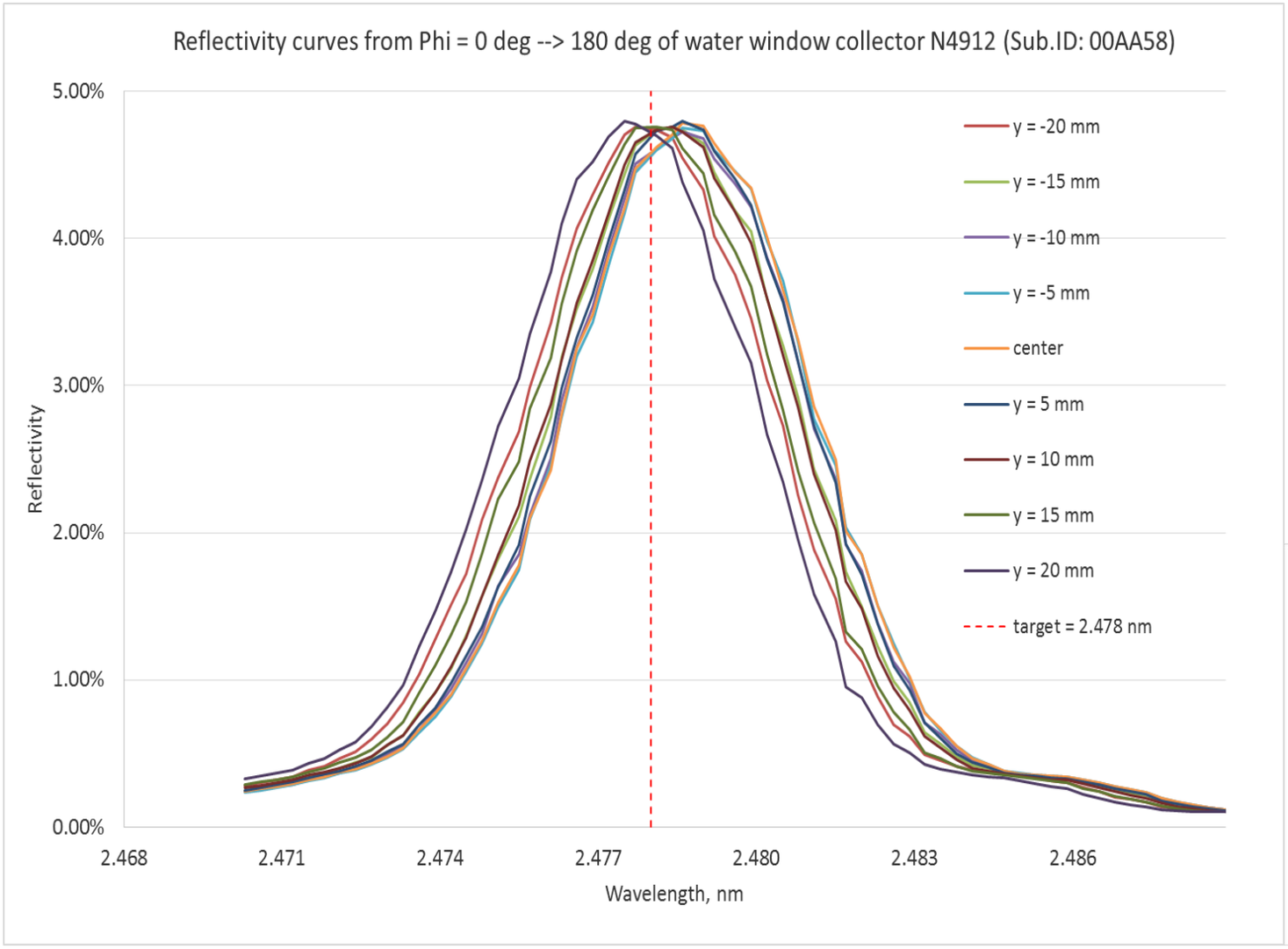
2016 multilayer collector mirror: Wavelength at different positions



Measured @PTB Berlin

optiX fab.

2016 multilayer collector mirror: EUV reflectance at different radii

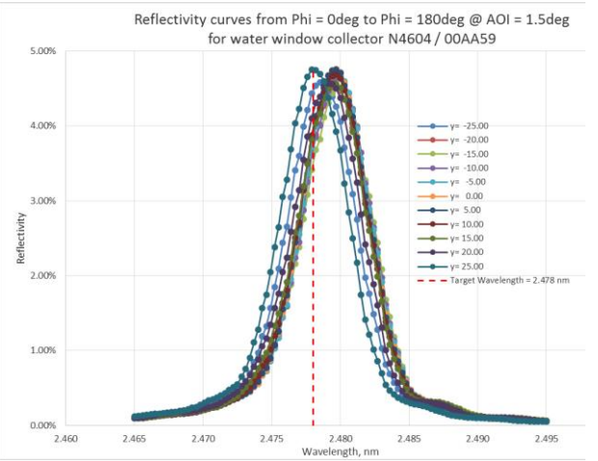


2015: R = 3.66 %

2016: **R = 4.58 %**

→ **25 % more photons!**

2015 status:



Measured @PTB Berlin

optiX fab.

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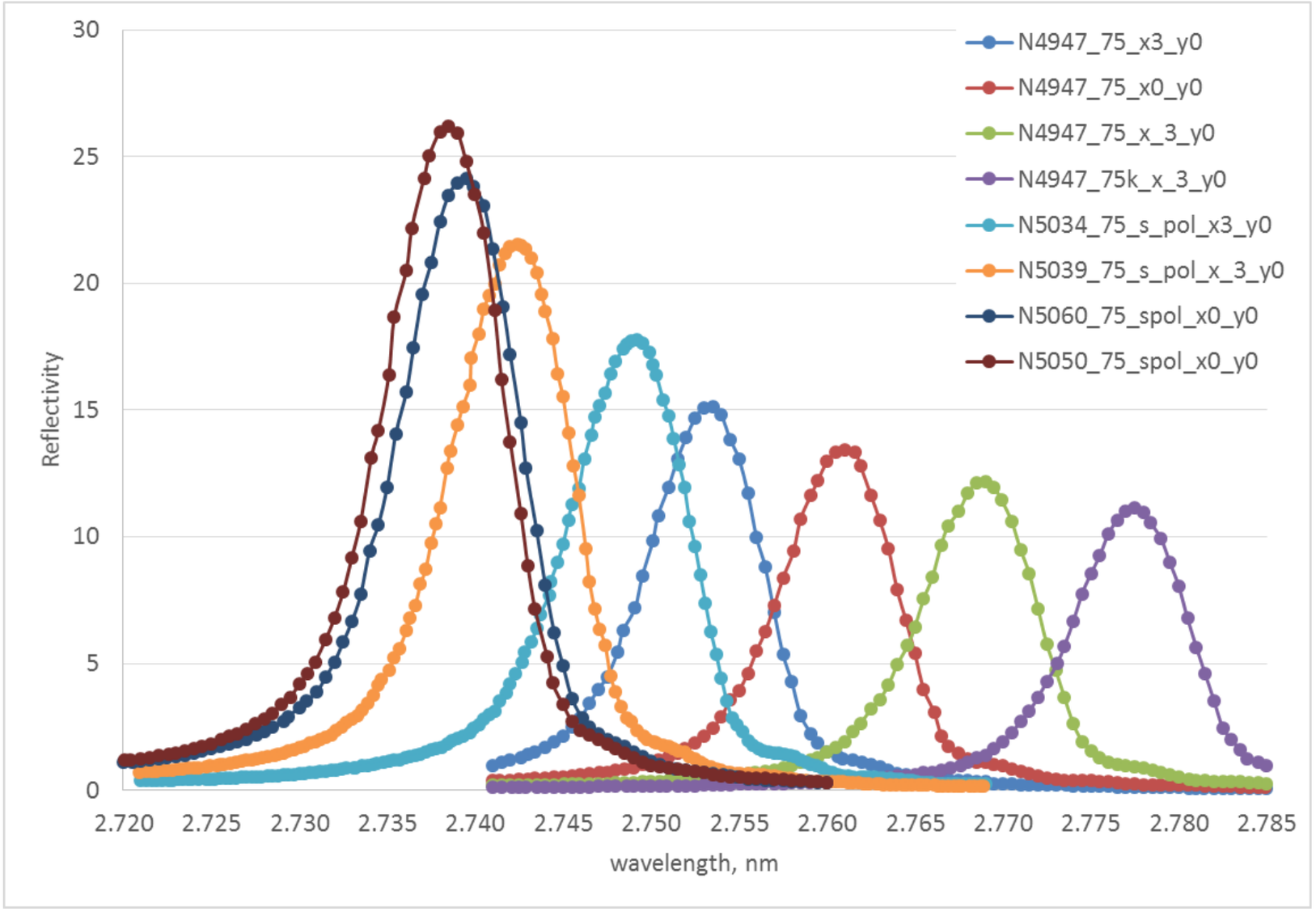
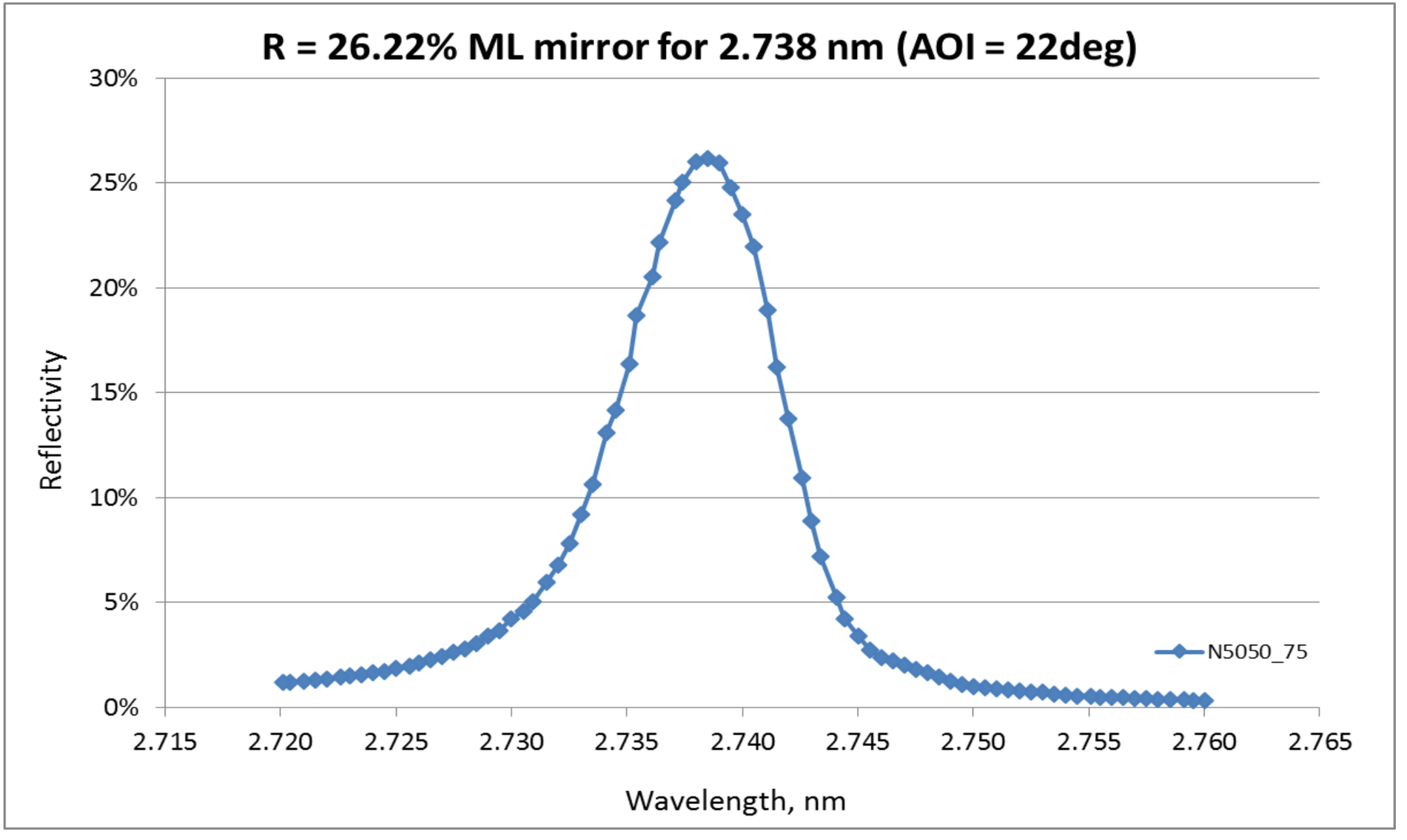
optiX fab.

Multilayer development for 2.74 nm turning mirror



optiX fab.

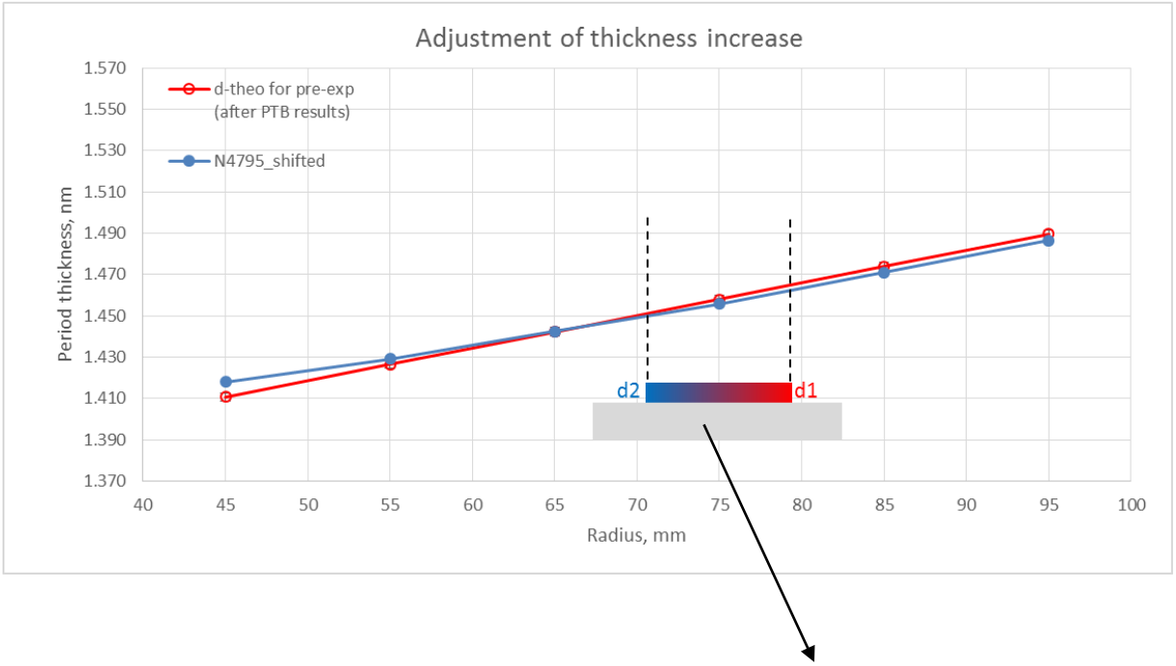
Multilayer development for 2.74 nm turning mirror

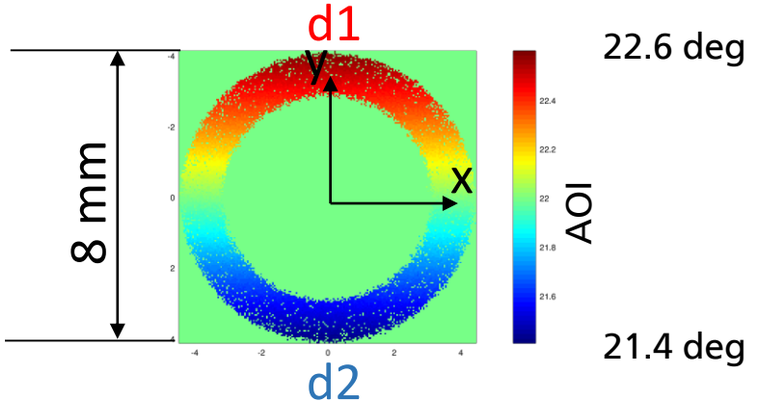


optiX fab.

Graded multilayer mirror for λ = 2.74 nm – d-spacing results

- Graded multilayer coating for turning mirror





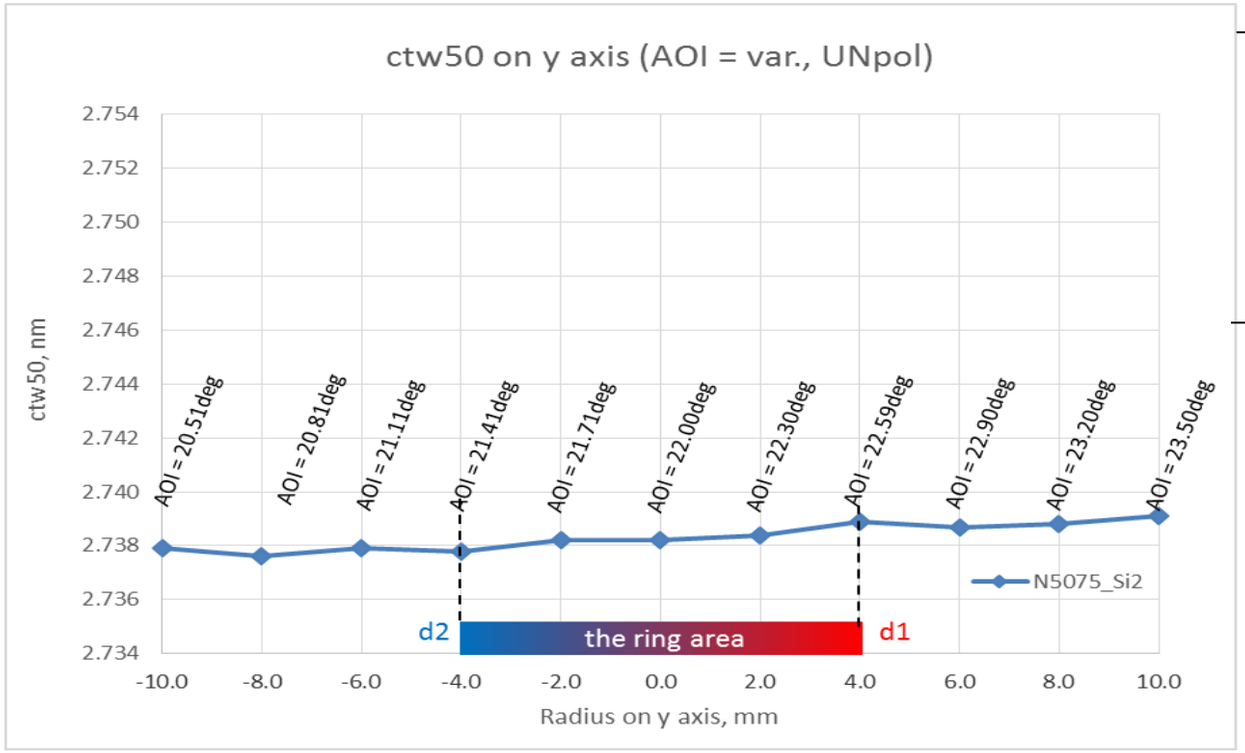
Period thickness

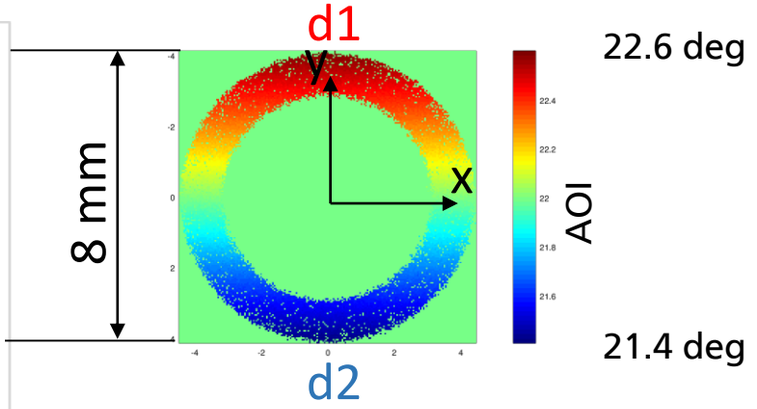
d1 > d2 according to AOI

- Diameter of plane Si substrate: 25.4 mm
- Increasing of thickness gradient: ~ 1% per 10 mm

optiX fab.

Graded multilayer mirror for λ = 2.74 nm – wavelength results





Period thickness

d1 > d2 according to AOI

- Center wavelength within the ring area: λ = (2.7383 ± 0.0006) nm

Measured @PTB Berlin

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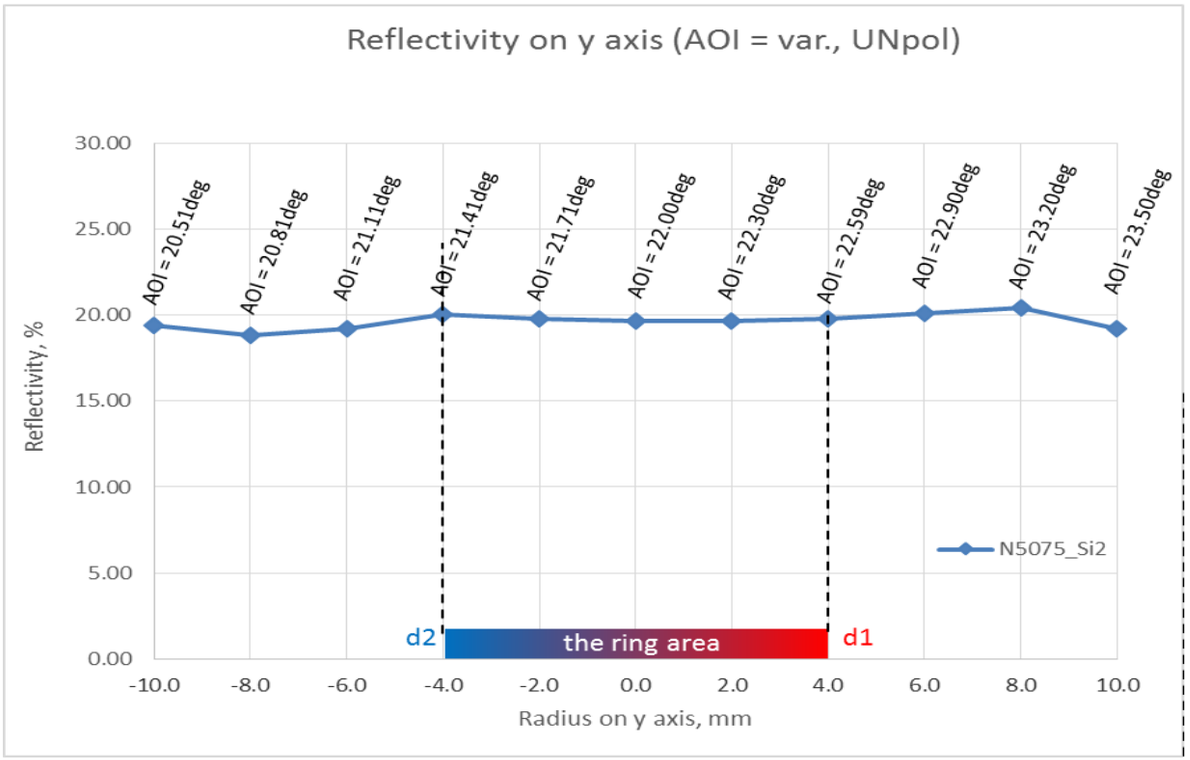
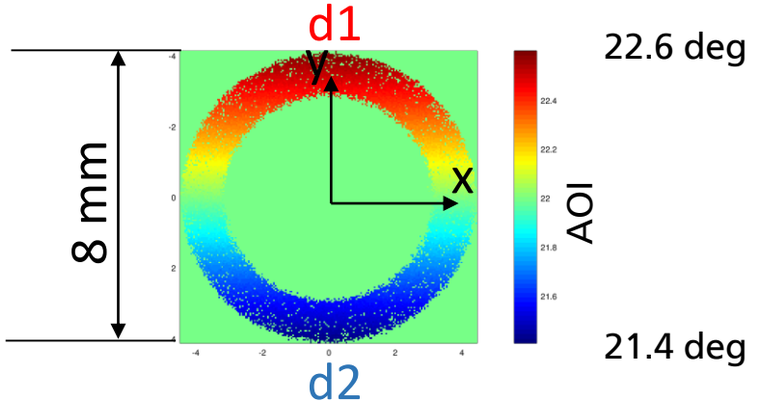
Graded multilayer mirror for λ = 2.74 nm – reflectance results





Period thickness

d1 > d2 according to AOI

- Peak reflectivity within ring area: R_{unpol} = 19.8 % @ AOI = 22 deg

  $R_{s\text{-}pol}$ = 24.1 % @ AOI = 22 deg

Measured @PTB Berlin

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Outline

- Introduction
- Multilayer collector mirror for 2.478 nm
- Multilayer turning mirror for 2.738 nm
- Summary

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Summary

- Fabrication of customized EUV multilayer optics from 2 nm to 100 nm
- Fabrication of customized hard and soft X-ray optics
- Reflectance level for water window region:

  R = 18.22 % @ 2.422 nm (AOI = 2.5 deg; s-pol.) – Cr/V with barriers
  R = 26.22 % @ 2.738 nm (AOI = 22 deg; s-pol.) – Cr/Ti with barriers

- Homogenous reflectence level for water window collector:

  R = 4.58% @ 2.478 nm (AOI = 1.5 deg; s-pol) – Cr/V with barriers

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Thank you.

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